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Automation, Information Sharing and Shared Situation Awareness

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ABSTRACT

Increasingly, the trend for military and other organisations is an increase in automation to improve the efficiency and effectiveness of staff in the workplace. In the military context, automated tools assisting in battlefield visualisation and mission planning may be implemented for these very purposes. Automation may, however, impact on the performance of military teams and affect the situation awareness (SA) necessary for good team functioning. This review examines the potential impacts and benefits of automation on information sharing, SA, planning, and team performance, as well as the concept of measuring SA. Several potential methods for measuring both shared and individual SA in various military contexts (ie. during field exercises, Command Post Exercises and in laboratory-based experiments) are then briefly outlined. It concludes with a brief discussion of the need for further examination of the impact of automation, the need for training of staff, and the reality of the benefits imparted by the tools themselves.

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Executive Summary

The current trend in military and other organisations appears to be an increase in the use of automation to improve the efficiency and effectiveness of staff in the workplace. In the military context, automated tools assisting in battlefield visualisation and mission planning may be implemented for these very purposes. Automation may, however, impact on the performance of military teams and affect the situation awareness (SA) necessary for good team functioning.

In this review, the potential impacts and benefits of automation on information sharing, SA, planning, and team performance are examined. In addition, the concept of measuring SA – which has been problematic in terms of the measurement of both individual and shared SA – is also considered. Several potential methods for measuring both shared and individual SA in various military contexts (ie. during field exercises, Command Post Exercises and in laboratory-based experiments) are then briefly outlined, along with their potential applications in the various military contexts.

The review then concludes with a brief discussion of several issues: the need for further examination of the impact of automation, the need for training of staff, and the reality of the benefits imparted by the tools themselves. The information contained in the review should form a foundation for considering the trialing of new or modified existing SA measurement techniques, which should lead researchers towards the development of a systematic method to assess the contribution of automated tools to the effectiveness and performance of teams.

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Contents

1. Automation: the way ahead for military decision makers of the future?

It is clear that there is an increasing emphasis on the provision of automation for military command and control (C2), in line with the general trend towards increasing automation throughout the 20th century. Automation is to be employed in many of the operational aspects of the military, from the decision-making processes utilised by the higher ranks to the soldier fighting the enemy on the ground. What is often at issue is the *effectiveness* of such automation: are these technological advancements being employed effectively, and are they facilitating the functioning of the Army?

In some cases, the answer to these questions may well be 'no'. This has been illustrated by automation-facilitated accidents – particularly those occurring within the Naval and Air Force elements throughout the world – as they have a higher reliance on automation due to their very nature. The USS Vincennes incident illustrates what can happen when automation exists, and yet the information provided via this means is either ignored by the users or interpreted in a biased manner. In this instance, an Iranian airliner carrying 290 people was shot down by the crew of the USS Vincennes in the belief – influenced by the fact that they had recently been under attack from gunships – that the approaching aircraft was a threat. A key problem in situations such as this has been suggested (Rochlin, 1998) to be the difficulty experienced by teams in maintaining an accurate shared understanding while performing with high technology in fast moving situations.

In recent years there has been an increased emphasis on research to inform the development of automated tools, particularly from the Human Factors perspective. This research should not be limited to the design of such systems and basic measures of their usability. The need for training in the effective use of automated tools (to facilitate fast assimilation and efficient performance within teams) should also be considered in the push to apply automation to the art of mission planning and warfighting. Additionally, there have been large bodies of work generated both at defence research organisations (such as DSTO [Australia], DCIEM [Canada], DERA [UK]) and at external organisations that may be contracted to do piecemeal defence work. A review of some of the work in this vein conducted at DSTO in recent years can be found in Seymour, Grisogono, Unewisse, Johnson, Krieg and Haub (2000).

This review examines a series of related issues, including the use of information for knowledge generation, the generation of situation awareness (SA), the mission planning process, the impact of automation on these processes, and the possibilities of enhanced planning and command capabilities with the implementation of automated decision support tools/systems. Potential evaluation methods for SA and indicator conditions (such as performance) are also discussed. This is in keeping with the aim of understanding the impact of automation, and providing a means through which to form recommendations to ensure that this impact is a beneficial one.

2. Knowledge and information use

It is well known that knowledge and information[1] — two distinctly different entities — are critical factors in the planning of missions and indeed in any decisions made by commanders with respect to the deployment of troops and equipment. It is also apparent that engineers designing automated decision support tools and/or systems need to consider the warfighter's point of view, particularly in terms of asking how such tools will assist the commander/planning team/fighter in reaching their goals and objectives more quickly and effectively, and with less binding of physical and cognitive resources than the current paper and pencil method. Too often, the implementation of automation has the potential to result in excessive or extraneous information being presented to the commander or planning team, which can increase the pressure experienced under time-constrained working conditions. Although experienced decision-makers tend to filter the necessary information and therefore do not suffer as much as inexperienced decision-makers, there still exists the potential for even these expert planners and commanders to be swamped by the excessive information provided by new technologies. As implied in a paper by Seymour et al (2000), a digital tool (for example, a computer display containing a map and all the relevant entities on the battlefield) can lead to information overload due to "...too much detail swamping a user and leading to poorer and slower decision making." This phenomenon has been noted by researchers under various conditions (including during microworld simulations such as 'FireChief') and is outlined in Omodei, McLennan and Wearing (2000) and Rooney, Kallmeier and Stevens (1998). These results do not, however, indicate that all 'digitisation'[2] is detrimental to operational effectiveness. It is simply that the application of technology to such processes as these requires care in terms of accommodating human capabilities and limitations.

When looking at the information needs of commanders, Kahan, Worley and Stasz (1989) indicate that commanders seek a dynamic image of the battlefield that will lead to an understanding of what actions are necessary. Depending on the situation, this image tends to be composed of between five and nine major components, including the traditional factors of METT-T (Mission, Enemy, Terrain, [own] Troops, and Time available). For the effective implementation of command, however, a commander's staff must — to some extent — also hold the mental image held by the commander: in this way, his staff can supply relevant and important incoming information in a timely and effective manner. This then necessitates a focus on the communication of information and/or knowledge within the C2 process, so that the communication of mental images can be facilitated.

[1] That is, 'information' represents the facts or data collected, while 'knowledge' represents the sum or range of what has been perceived/discovered/learned. Knowledge therefore represents the persons' understanding of information they have obtained or been presented with, and implies that some type of fusion/integration/processing of raw information has taken place.

[2] 'Digitisation' is the application of information and communication technology in the battlefield which allows data to be entered directly into a system by sources, and automatically disseminated to users

Information is obtained from multiple sources throughout the course of mission planning and execution, though the rate of information influx tends to vary during the fighting phase of battle activities. Enemy locations and activities are reported as they come to hand, as are the status of friendly units, but there tends not to be a continuous flow of such information because battle is not a smooth, continuous flow of fighting. This new information must be integrated into the picture the commander holds of the battle itself, and then applied to adjust courses of action when necessary. This integration expands the commander's knowledge of the situation and generally facilitates his ability to predict necessary courses of action.

3. Situation Awareness

Situation awareness is a term used originally in the aircraft community, and achieving it is perhaps the most difficult aspect of an operator's work. It has been defined by Endsley (1988: 97) as: "...the perception of the elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." It is therefore clear that SA is necessary in order for people to perform tasks effectively (Endsley, 2000). Dominguez (1994) gives a similar definition, but places more emphasis on the impact of awareness on cue extraction and directed perception (i.e. its contribution to attention). For Dominguez (1994: 11), then, SA constitutes a "continuous extraction of environmental information, integration of this knowledge to form a coherent mental picture, and the use of that mental picture in directing further perception and anticipating future events." Thus, SA appears to involve three hierarchical levels linked by various cognitive processes. These levels are:

- Perceiving critical factors in the environment [level 1],
- Understanding what those factors mean (in particular when integrated together in relation to the person's goals) [level 2], and
- An understanding of what will happen with the system in the near future [level 3].

The higher levels of SA allow operators to function in a timely and effective manner when the demands of high workload periods prohibit effective use of explicit coordination methods (Endsley, 1996). Level 3 SA cannot be developed or employed, however, unless levels 1 and 2 are already well established in the individual.

This definition of SA refers to *individual* SA: it is not enough for successful mission planning or execution, however, that SA exists individually in planning team members. It must be *shared* SA in order to facilitate effective planning based on a common understanding of both the situation and the implications of any actions/orders for action. In addition, it is not adequate to simply share a few common elements of SA between team members or across teams. Shared SA should be a relatively complete and integrated

picture of the current situation and the potential developments to that situation, as well as the possible tactics to be used in the event that those developments *do* occur.

3.1 Factors in shared SA

Situation awareness in aircrew members from a variety of aviation communities (i.e. military, general and carriers) was examined by Prince and Salas (1998) via a series of interviews. The outcomes of these interviews indicated that there were four main factors contributing to the development and maintenance of SA in these crews, and that these varied in importance according to the level of experience of the pilots. Those with less than 1000 hours flying time considered that *flight preparation* (*planning*) and *communication* were the two most important factors for SA, while pilots with more than 1000 hours tended to emphasise *leadership* and *adaptability* behaviours were more important for team/shared SA (although acknowledging that communication and preparation were also of importance).

Thus, these interviews revealed that aircrew members perceived team or shared SA to be achieved and maintained through a combination of individual SA and the four factors (termed 'process skills') outlined above (Prince and Salas, 1999). This has been confirmed by research findings indicating that crew members' SA is strongly related to the team process skills identified by the interviews (Brannick, Ellis, Prince and Salas, in preparation).

The concept of shared mental models is a construct that can help to provide an understanding of the relationship between team processes and shared situational awareness in teams (Salas, Stout and Cannon-Bowers, 1994). In terms of what aspects of mental models may have to be shared in order to facilitate the team process, researchers have proposed that successful teams share knowledge of several common factors such as overall task and team goals, individual tasks, team member roles, and the team members themselves (Cannon-Bowers, Salas and Converse, 1995). Developing this proposal, Converse and Kahler (1992) suggest – based on an extensive literature review - that there are three types of knowledge that can be shared by team members, and that these are *declarative, procedural* and *strategic*. They defined these three types in the following way:

- *Declarative:* these models contain information about the concepts and elements in the domain and the relationships between them. They include knowledge of facts, rules relationships and the common factors listed by Cannon-Bowers et al (1995) previously.
- *Procedural*: these models store information about the steps to be taken (and the order in which to take them) in order to accomplish various activities. It is essentially timing and sequence information.
- *Strategic:* these models consist of information that is the basis of problem solving, like actions plans to achieve goals, knowledge of the context in which to implement the procedures, actions upon failure of the proposed solution, and responses to absent information. This is a compilation of declarative and procedural knowledge, and through team experience this knowledge allows for automatic performance (and

expert team performance) through the use of the correct task strategies (Converse and Kahler, 1992: pp. 5 – 6).

In this scheme then, the strategic model applies knowledge stored in the procedural and declarative models within a dynamic mission context to allow an understanding of the necessary actions, cues and sequences needed to achieve the team and task goals (Cannon-Bowers et al. 1995).

In summarising the relevant SA-related literature, Cannon-Bowers et al. (1995) make the following important points about the nature of SA:

1. Mental models are important for individual SA.
2. Shared mental models are important to team performance because they allow team members to form the necessary explanations and expectations of team and task actions, and
3. Team (shared) SA is important to team performance.

Clearly, then, a shared mental model is an important prerequisite to attaining shared SA (Sarter and Woods, 1991). Simply having a shared mental model is not a guarantee that adequate shared SA will be developed, however. There are other issues (like shared cognition, for example) to be considered before the process of transforming shared information into shared SA can be understood.

3.2 Challenges to shared SA

Shared SA is not simple to develop, and can be adversely affected by a range of factors, including stress, mental work over- or under-load, system design, complexity, human error in perception, and automation. For example, it is well documented in psychological literature that a certain level of stress can enhance performance, but that excessive or prolonged higher stress levels can have the opposite effect due to demands on attentional processes and the physical side effects (Hockey, 1986). Thus, a lower attention capacity and narrowing of attention spans (leading to concentration on a limited number of factors), disruptions of scan patterns, and premature closure (making a premature decision without considering all available information) can be problematic, particularly for level 1 SA (Endsley, 1999). In addition, a decrease in working memory capacity and hindrance of information retrieval can also adversely affect SA (Hockey, 1986).

Errors in both individual and shared SA can be attributed to various factors or behaviours, not the least of which could be the introduction of automation. Endsley (1995) has created a taxonomy of SA errors (see also Endsley, 1999). These are categorised into the three levels of SA, and the percentages of SA error accounted for by the various behaviours is displayed in tabular form. The three categories are as follows:

SA	**Error Type**
Level 1:	Failure to correctly perceive the situation
Level 2:	Failure to comprehend the situation
Level 3:	Failure to project the situation into the future

By far the highest percentage of SA error overall is accounted for by a failure to monitor or observe data (which is in the level 1 SA category); in the level 2 SA category, the highest percentage of error is accounted for by use of an incorrect mental model. In the level 3 SA category, it appears to be poor or over-projection of the current trends leads to the majority of SA errors. Care must be taken, however, to ensure that these problems with SA are not simply labelled 'human error', and that researchers differentiate machine-related and human-related causes for SA error (Baxter and Bass, 1998).

It is conjectured that automation can adversely affect SA due to the tendency for automated tools to put the human 'out of the loop'. Automation could result in pilots being slower to detect and respond to problems, for example; however automation may not have a consistently adverse effect across the board. It may prove beneficial in situations where (a) automation enhances information or data fusion with no additional workload for the system operator, or (b) where either/both mental or manual workload can be reduced. It is these types of benefits that are sought for the military community in particular, as any improvements in the speed of information processing may have flow-on effects leading to shorter decision cycles. These may therefore lead to decision and planning operations (followed by the execution of missions) being conducted within the decision cycle of the enemy force by friendly forces. Obviously a time saving at this preliminary stage should provide advantages for friendly forces in terms of their ability to conduct successful missions.

Another challenge to the development and maintenance of SA in teams is lack of appropriate communications between members. Schwartz (1990) asserts (in terms of aircrew) that although each member in the cockpit has individual SA, the group's shared SA can be limited by the working memory of the individuals and so must be constructed and updated by information updates from each of the team members in order to maintain an appropriate level of SA. In this way, the crew's SA is believed to be a direct consequence of (among other things) the communication ability of the crew. This is supported by findings from Orasanu (1990) in a study of crew decision-making. She found that crews that performed better on the simulated mission made a significantly greater number of SA statements than did crews that performed poorly. Mosier and Chidester (1991) studied communications during emergency situations, proposing that the effects of differences in communications would be more apparent under these conditions. They found that the number and type of communications did in fact relate to crew performance, and that crews collected information before as well as after the decisions were made, indicating that although the problem might have been solved, it was not forgotten. Further research to clarify the role of communication in SA development and maintenance needs to be conducted, as the research to date has not conclusively elucidated the role it plays in this vital component of teams.

3.3 The concept of measuring SA

It is not adequate to discuss SA, shared SA and the effects of various factors on these constructs without a discussion of the means available for measuring the construct itself. This is where the main difficulty of research in SA is found: *individual* SA is a relatively difficult construct to measure, and thus *shared* or *team* SA presents somewhat more of a problem in terms of the added complexity of group dynamics.

An additional difficulty is quantifying how much SA is "enough". Endsley (2000) states that SA and performance measures are only linked probabilistically, and that there are no set thresholds of SA to guarantee a given level of performance. Other factors may assist in determining outcomes, and so a team with a low level of SA may perform well due to a high degree of luck. She proposes that an answer to this is to be concerned with relative levels of SA. In terms of the automation issue, this would mean an increase in SA (after the addition of new technology) relative to the level measured prior to this introduction. Measurement should also be against the "ideal" SA: that is, perfect knowledge on all relevant aspects of a situation, with no gaps or holes in it. This means that SA spans a broad set of constructs and is not a simple concept, which makes the job of measurement and enhancement of SA a complex one. In addition, actual SA tends to be a subset of the achievable SA, which is again a subset of the ideal SA of any situation (Pew, 2000): given the complexities of the world (and particularly the military battle situation), perfect SA is generally not feasible, and operators would be in the higher percentages of achievement if they did indeed achieve the entirety of theoretically achievable SA.

When dealing with individual SA, Entin (1998) states that an individual's level of SA will be partially determined by the quantity and quality of the information available *and* by the individual's ability to utilise the important information sources and fill in for missing, imprecise or incomplete information. Entin (1998) and Entin, Serfaty and Entin (1995) list reasons for lowered SA as encompassing factors such as lack of anticipation of — or attention to — vital factors (due to lack of awareness of the importance of these factors, or attention being focused on other things). Entin (1998) gives two types of SA measure: *high-level* and *detailed*, both of which are taken at multiple points in a simulated attack. High-level measures assess SA according to subjects' responses to general questions about the evolving tactical situation. The detailed SA measure is based on questions about elements of the situation (in a way similar to measures derived from the Situation Awareness Global Assessment Technique [SAGAT], which is based on a broad-ranging assessment of operator SA requirements) (Strater and Endsley, 2000).

Measurements by Entin (1998) suggest that detailed SA is more integrated and less ambiguous during the planning phase, as the situation is more static and time is not perceived to be a critical factor. At this point, there is more time available to fine tune the details of SA and resolve any ambiguity or uncertainty present. As the mission proceeds, however, the situation becomes more fluid and events occur more rapidly. Individuals may not have time to integrate all the incoming information into a coherent picture, so the level of detailed SA is less consistent at later points in the mission. High level SA, by

contrast, did not show this pattern and supported the notion of strong relationships between levels of SA in adjacent phases (i.e. the planning, ingress and battle position phases) (Entin, 1998: 251 – 252). Entin suggests that this may indicate a difference in the cognitive processes in the two types of SA. That is, *high level* SA may depend more on the accuracy of the individuals mental model of the situation, while *detailed* SA may depend more on the individual's perceptual skills, memory and ability to extract and integrate specific pieces of information.

3.4 Possible measures of SA

Two types of SA measure emerged from Entin's (1998) study of detailed and high level SA. Measures of detailed SA were based on the responses of subjects to questionnaires that included questions designed to capture specific elements of the situation. These elements included current and projected locations of specific friendly and enemy units, status and relative location of ownership, and the expected direction of enemy movement. Questions about location or direction of movement were answered on the tactical simulation display, with other questions being answered in writing. Subject matter experts (SMEs) were used to determine the precision required for a correct response (Entin (1998) p. 251). The subjects' answers were evaluated on a four-point scale in terms of correctness, and a weighted average of the scores on individual questions was computed to give an overall measure of detailed SA.

Measures of high-level SA were gathered via a verbally administered questionnaire containing between five and eight open-ended questions about aspects of the tactical plan, constraints imposed by geographic situation, implications of enemy actions, and indications of the plan's success. The high-level SA measure was derived by subject matter expert (SME) evaluation (on a four-point scale) of subjects' answers about the current and evolving tactical situation on the five components of SA (i.e. accuracy of friendly and enemy dispositions, assessment of changes to friendly and enemy situations over time, and grasp of the evolving tactical plan). The overall score was obtained by taking the arithmetic mean of the five component scores.

There are several means by which SA can be measured, according to Pew (2000: 38 - 43), which fall into the following categories.

Direct systems performance measures. These are only applicable in very limited situations. The use of scenarios specifically designed to create openings for unobtrusive performance measures to be taken on specific SA can, however, be effectively substituted for these. Use of such scenarios may involve the introduction of unexpected events, and measuring the time taken for the subject to react, as well as the quality of the reactive measures taken. Alternatively, disruptions intended to disorient the team or operator can be introduced. The team's or operator's recovery time and the success of recovery tactics taken can be measured.

Direct experimental techniques. This is the most commonly used measurement method, and involves using queries and/or probes along with measures of information seeking during ongoing task performance. This does, however, require that the pace be relatively slow or that frequent periods of inactivity are available. Another common method of performing these direct experimental techniques involves freezing the scenario/simulation and asking the necessary questions before beginning the scenario once more (as in the SAGAT technique formalised by Endsley, 1988). Problems here include the disruption caused by the freeze technique and the possible alteration in behaviour due to subjects expecting the probes (e.g. preparation for future and increased focus on potential probe issues). [3]

Verbal protocols. This method involves the direct recording of information from observers or subjects during or immediately after an exercise, or from videotape records of the exercise. Here, subjects may be asked to think aloud or explain information as they work. This method is most valuable at the beginning of an evaluation when concepts are still being refined.

Subjective measures. These methods include self-assessments, expert judgements, peer ratings, and supervisor or instructor ratings. The best of these techniques to date appears to be the self-administered SA test, the SART (Situation Awareness Rating Technique), involving a three scale subset the results of which are combined via algebraic equation to produce an overall estimate of subject SA (see Taylor, 1990).

In addition, the SALIANT methodology developed by Muniz, Stout, Bowers and Salas (1998) and validated by Bowers, Weaver, Barnett and Stout (1998) has also been put forward as a successful technique for producing checklists for behaviourally assessing SA. The SALIANT acronym refers to Situational Awareness Linked Indicators Adapted to Novel Tasks, and involves the use of a theoretically based list of behaviours (known to be associated with SA) to assess team behaviour. A set of team behaviours theorised by Muniz et al (1998) to be linked with team SA is included in Table 1 below.

As Table 1 shows, there are many observable behaviours that can potentially be used as indicators of team or shared SA. These are not complete in their inferential validity, however, and should be supplemented by some form of direct questioning of subjects, which may include a "video walkthrough" technique if circumstances allow. This is particularly true in the case of shared SA during the battle itself. It may be that, during planning sessions, the unobtrusive methods yield adequate information for the observers /researchers to enable SA measurement.

[3] Please refer to French and Hutchinson (2002) for detail on the modified SAGAT methodology applied to the measurement of SA.

Table 1. Behavioural indicators of team situation awareness

Demonstrated awareness of surrounding environment
➢ Monitored environment for changes, trends, abnormal conditions ➢ Demonstrated awareness of where he/she was
Recognised problems
➢ Reported problems ➢ Located potential sources of problem ➢ Demonstrated knowledge of problem consequences ➢ Resolved discrepancies ➢ Noted deviations
Anticipated a need for action
➢ Recognised a need for action ➢ Anticipated consequences of actions and decisions ➢ Informed others of actions taken ➢ Monitored actions
Demonstrated knowledge of tasks
➢ Demonstrated knowledge of tasks ➢ Exhibited skilled time sharing attention among tasks ➢ Monitored workload ➢ Shared workload within station ➢ Answered questions promptly
Demonstrated awareness of information
➢ Communicated important information ➢ Confirmed information where possible ➢ Challenged information when doubtful ➢ Re-checked old information ➢ Provided information in advance ➢ Obtained information on what was currently happening ➢ Demonstrated understanding of complex relationships ➢ Briefed status frequently

This would be preferable to applying more direct questioning methods, as the less obtrusive the data gathering technique, the higher the quality of the data. Minimising the subjects' contact with the concepts researchers are trying to measure, and attempting to create the least possible disruption to the team processes are desirable here. More obtrusive measures may produce measures of what the subjects think the researchers want to see or hear, rather than a picture of what would actually have been the case without researcher interference. This type of problem has been combated by researchers such as Endsley (2000) (for example) via the use of randomised and comprehensive questions during the use of the freeze technique. In order to explore the measurements possible during planning, the concepts involved in planning will now be explored in more detail.

4. Mission planning

The architecture of C2 operations is important to the understanding of which functions will be important in the mission planning process, and which of these may be effectively enhanced by the addition of automated tools to the process. Noble (2000) has represented this architecture diagrammatically, as shown in Figure 1. It is apparent in this figure that one of the keys to effective operational architecture is the manner in which it integrates situation assessment, planning and execution. In this diagram, "understanding" refers to the understanding of how the situation impacts the mission, "decision" is embodied in the commander's directive and includes the clear expression of intent, and "feedback" refers to the information needed to determine how well the plan is progressing and to identify opportunities and risks (Noble, 2000).

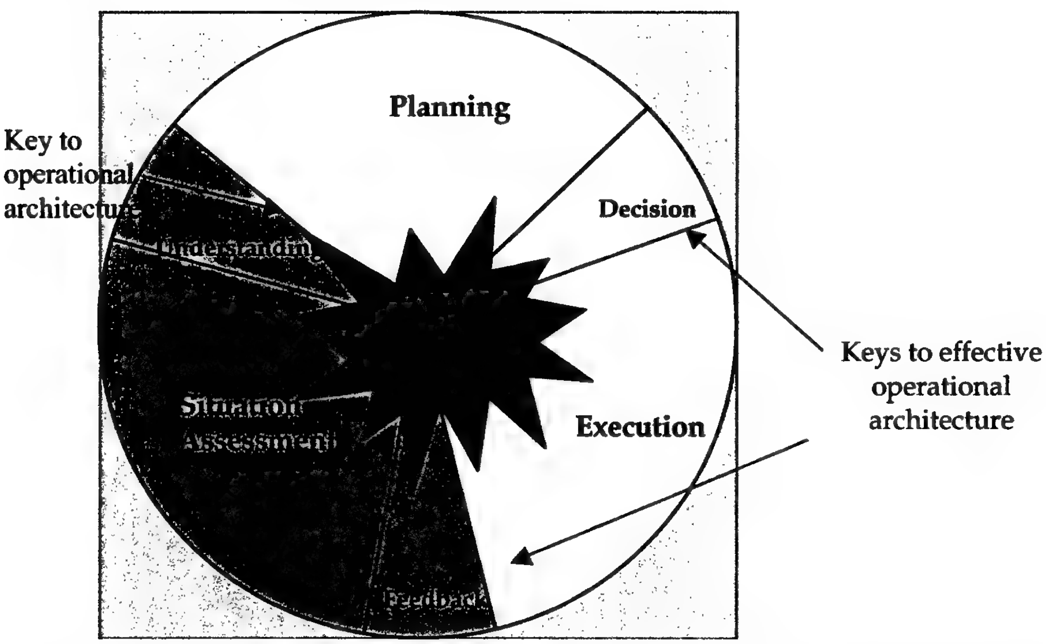

Figure 1: Elements of C2 operational architecture, emphasising richly coupled, dynamic interfaces (adapted from Figure 2 in Noble, 2000)

On examination of the 'lessons learned' data from the Marine Corps MAGTF Staff Training Program (1999), it was discovered that most of the identified operational shortfalls existed due to human performance limitations. Thus, four groups of recommendations relating to these shortfalls were put forward as follows:

a. Building and sharing a common picture
b. Developing mission strategy/concept and identifying needed tasks
c. Establishing conditions needed for adaptive control
d. Expressing intent in a clear directive (Noble, 2000: 10)

Clearly, item (a) in the list above — building and sharing a common picture — is essential to shared SA. It emerges from the team's performance of the situation assessment functions that are a prelude to the planning phase, and is susceptible to the types of human errors inherent in all conceptual entities that rely on multiple/shared human perceptions. Differing interpretations of a situation (or an aspect of a situation) or the actions necessary to deal with that situation may lead to quite different individual SA, or team SA if referring to intra-team shared SA.

4.1 Situation assessment and planning functions

Noble (2000) also outlines a series of mid-level situation assessment and planning functions that are divided and organised under higher level function headings as set out in Table 2. It can be observed here that the situation assessment functions lead directly into the planning functions (and outcomes). That is, the SA that must be maintained by the mission planners should be as complete as possible to facilitate effective planning outcomes. This relies on the adequacy of the situation assessment, particularly in terms of the information being entered into the picture, and the knowledge this information then generates. In addition, the use of a clear intent from the higher commander is vital to the production of a mission plan, and thus the process relies heavily on the integration of this information with the SA-producing information coming in from other sources.

On examining the planning functions, it is evident that the planning team would rely on a well-developed and maintained level of shared SA in order to carry out many of these planning functions. This is particularly true in the case of coordination with other distributed team members or teams, and can be difficult to maintain under these circumstances. This is one of the conditions under which a visualisation tool, which provides a fast updating visual image[4] to disparate teams, can be most effective in enhancing SA.

Planning functions do, however, enjoy a positive relationship with the development and maintenance of shared mental models in team members, according to Stout, Cannon-Bowers, Salas and Milanovich (1999). These mental models in turn contribute to both the development and maintenance of shared SA in teams. As such, mission planning promotes the sharing of information, priorities and goals related to the task requirements, and team member's (or team's) roles can be clarified prior to mission commencement. Stout et al (1999) found that effective planning prior to mission execution enhanced the effectiveness of teams (see also Sterling and Lickteig, 2000).

[4] An image that combines text, symbols, and maps, for example.

Table 2: The mid-level C2 functions (modified from Table 1 in Noble, 2000)

Situation Assessment Functions

S-1. Understand situation assessment requirements.
- a) Identify elements of requested information
- b) Review context of requested information

S-2. Gather the information
- a) Identify the information to be gathered
- b) Formulate and make requests
- c) Assess information quality
- d) Screen, organise, and forward information

S-3. Estimate the situation
- a) Assess and track the environment (weather/terrain, social/economic/political situation)
- b) Project environment
- c) Estimate and track threat location and identity
- d) Estimate and track adversary force, intelligence, surveillance and reconnaissance (ISR), logistics, communications, facility status, organisation, activity and beliefs
- e) Estimate adversary objectives, vulnerabilities, Courses Of Action (COAs), and plans
- f) Project the threat, including possible COAs
- g) Estimate own force location and capabilities, the status of own ISR, logistics, communications and facilities
- h) Estimate own force vulnerabilities and opportunities
- i) Project own forces, including strengths and vulnerabilities

S-4. Manage, integrate and distribute the situation picture
- a) Provide information assurance
- b) Manage uncertainty
- c) Assemble and integrate information for situation picture
- d) Manage inconsistencies among geographically distributed pictures
- e) Tailor picture to support decision making
- f) Share the picture

Table 2 cont'd.

Planning Functions

P-1. Prepare for planning
a) Understand mission and tasks
b) Form planning team

P-2. Develop strategy
a) Understand objective trade-offs
b) Understand the situation
c) Develop concepts for achieving goals
d) Identify goal, assets, constraints, phases, and contingencies
e) Select COA

P-3. Make / revise tentative plan
a) Decompose strategy to task and ID success conditions
b) Identify needed assets: equipment, information, consumables, and organisations
c) Determine boundaries (geographic, ROE)
d) Schedule tasks and assets (time, order)
e) Plan for automated and contingent decisions
f) Plan for execution monitoring and success forecasting
g) Evaluate plan: suitability, feasibility, acceptability, and robustness

P-4. Deconflict, finalise, and promulgate
a) Review and coordinate with operational echelons and resource managers
b) Articulate intent
c) Develop directive
d) Promulgate directive/share plan

4.2 Potential benefits of automated decision making tools

Automated decision making tools may also be labelled as 'automated SA tools' and 'battlespace visualisation tools' or 'visualisation tools' in various contexts. In essence, their function and design is intended to enhance the processes military staff engage in when making decisions regarding flight plans, ingress or egress routes, potential threats from enemy forces and a host of other critical issues. The types of visualisation tools currently being developed by many researchers world-wide may vary, however the tools referred to in the remainder of this review will be visualisation tools intended to assist commanders and their staff in generating a dynamic and comprehensive image of the battlefield and the battle itself.

When considering the potential uses for visualisation tools, several factors must be taken into account, which can then expand into related areas such as team training:

- Is the tool relatively easy to learn to use?
- Is it relatively simple to recall the instructions for use under conditions of high time pressure/stress, and low training levels?
- Does the tool provide all the functions previously carried out manually — and if not, why not?
- Does the tool provide additional useful functions, which are difficult or impossible to carry out manually?
- Does the tool facilitate information/knowledge sharing between team members and individual teams?
- Does the tool improve the efficiency of planning?
- Does the tool interfere with or aid the uptake, processing and dissemination of situation relevant information/knowledge?

A major problem with visualisation tools – as identified by Mills (2000) – has been their tendency to interfere with team performance during the initial introductory stages. This can often be the result of attempts to integrate somewhat complex computer technology into situations where the users have varying degrees of experience and competency with such devices. In this way, there can be disruption in smooth team functioning due to the shift in emphasis from the familiar manual methods to the somewhat unfamiliar digitised methods. This disruption can – it is predicted – be overcome with training and increased system and tool familiarity, and development of such tools is ongoing in order to provide a product to the military that fulfils their requirements and can be used with a minimum of frustration and stress.

Currently, different iterations of the various visualisation tool solutions tend to include functionalities which have been flagged as potentially important (or at least desirable) by software developers. There has also been input from some members of the military establishment, and these will be taken into account in the development process. Such current developments include capabilities such as 3-D fly throughs, representation of potential ingress routes, and the display of threat domes. Line of sight tools are also becoming common to many of these visualisation tools. Future developments should include progress towards ease of use, while still incorporating the more comprehensive aspects of this technology. It seems that adding complexity to the mission planning (or any other) function by adding complicated software tools with non-intuitive means of control may hamper the very functions that researchers are currently attempting to enhance.

5. The impact of technology on planning

The impact of technology (eg. planning tools and automated decision aids) in terms of distributed teams – i.e. where several members are situated in separate physical locations – should be considered in light of the combined operations of ground and air teams. These land-air systems (such as ground units combined with Armed Reconnaissance Helicopters [ARH]) need both effective mission planning and communication of these plans to the relevant operators. That is, for such teams to function as normal teams would, the updating of plans and tasking of units/squadrons must be as efficient as they would be for teams located at a single site (Gregory and Kelly, 1998).

Observations of both air and ground mission planning suggest that these two processes involve somewhat different emphases. That is, while ground teams tend to favour extensive pre-task discussions and mission planning to reduce the amount of information exchange needed during the mission, air teams tend to focus more on the effective use of communication during actual engagement with enemy aircraft (Cook, Angus and Campbell, 1999). This is due to the need for aircrews to identify, evaluate and execute plans while in the air, which leads to a different operational approach to information sharing. Thus, mission planning for distributed teams (encompassing both ground and air defence) must take into account these different emphases and ensure that the needs of both ground and air teams are met. It is possible that the introduction of automated tools for increasing the efficiency of planning by ground command teams can enhance the operations of combined/distributed teams by allowing the faster processing and representation of incoming information, as well as the creation/modification of mission plans and tasking for air defence and reconnaissance craft (eg. the ARH squadron). In this way, the capacity will then exist to draw map overlays relatively quickly and then swiftly pass them to the necessary recipients (cf. the manual draw and copy method).

According to Cook, Angus and Campbell (1999: 239) "the merging of air defence and ground attack roles has allowed users and developers to accept that components of each mode of operation can be adopted with some attrition of tasks which were perceived as redundant in light of new technologies". It should then be possible for the introduction of visualisation tools to provide avenues for enhancing the way that incoming and processed information are represented to the members of planning teams. In addition they can result in an enhanced picture of the situation for the commander, which may lead to enhanced team SA. Thus the implementation of automation in a planning context can potentially be highly effective in improving the team function and the outcomes of the planning process in terms of both the time to plan and the actual plans themselves.

5.1 Automated visualisation tools: the potential benefits

The new visualisations made possible by the introduction of technological advances into the planning process have the potential to make the design and export of mission plans to other operators in distributed environments more efficient than ever before. Some of the

technological advantages provided by the new tools include 3D fly-throughs of prospective mission plans. These can be advantageous for pilots and ground crews in providing information on the needs relevant to the mission being flown. The necessary information for preferred flight paths could include such things as possible enemy sight lines, safe or relatively well hidden movement routes, the distances to be covered, and the resupply necessary for weapons, for example. Figure 2 shows two possible line of sight (LOS) displays from the perspective of either a helicopter (probably flying 'low and slow') or an elevated feature (such as a mountaintop). The lines of clear vision and those areas hidden from view are easily discernible in these figures, and would form vital knowledge for the planning of optimal flight paths according to the last known intelligence reports available to the pilots/planners regarding enemy locations.

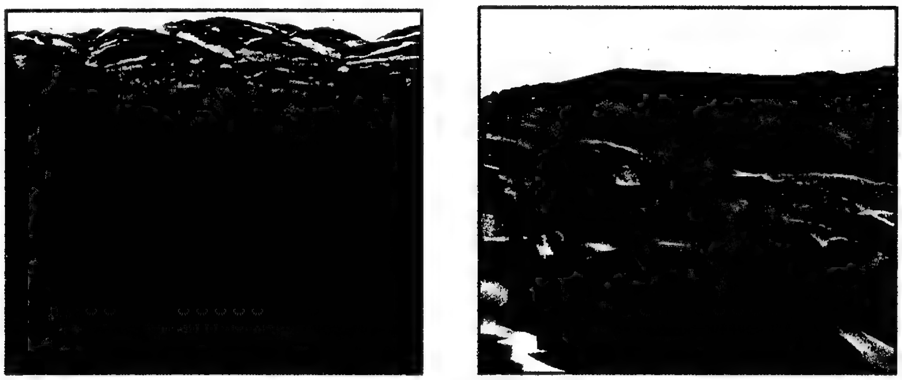

Figure 2 a and b: Example of LOS tool displaying visibility from (a) an elevated distant perspective and (b)from a close and elevated perspective (From Kirby et al (2000) Figures 7b and 7c respectively)

The increase in the amount of information able to be displayed in a functional manner may be perceived as a benefit - as long as the added information does not create clutter or mental work-overload for the tool operators (i.e. the planners and pilots). A study by Smallman, Schiller and Mitchell (1999), for example, found that when using 2-D and 3-D display formats, the 3-D format resulted in enhanced SA for the attributes of altitude and attitude. Thus, this would indicate a nett advantage for planners and pilots in using a tool with 3-D capability. It was observed, however, that this improvement was not immediate. Thus, a time lag in noticeable positive effects should be taken into account when evaluating the impact of any automation on performance and SA. The benefits of 3-D visualisation on warfighter's understanding of the battlespace have been supported by a cognitive task analysis carried out by Eddy, Kribs and Cowen (1999). This task analysis indicated, "... a 3-D display could provide a succinct, comprehensible and readily discernible presentation of the common tactical picture." (p. iii). Such 3-D representations can be seen in Figure 3.

It can also be understood that the introduction of visualisation tools can impact the SA of the teams (or teams of teams) endowed with the tools. The potential effect of full or partial automation is discussed in the next section.

Figure 3 a and b: Possible 3D battlespace visualisations (From Kirby et al, 2000: figures 1 and 2)

6. The impact of automation on SA

While in many cases automation has provided the desired benefits and extended the system functionality beyond the reach of human capability, there has been a change in the role of the human operator (Endsley, 1998) that needs to be addressed. When humans become relegated to monitoring functions (that is, simply ensuring that the automated tools/systems are performing adequately), they tend to lose sight of both the incoming information and the processes used to turn that information into knowledge. One of the benefits of the current manual system of planning and information processing is that the human stays 'in the loop', and maintains up to date awareness of what is going on. It is important in the current climate of piecemeal automation (i.e. partial automation of a larger process) that humans — in their role as integrators — can maintain awareness of the processes occurring at all stages of operations, and the state of affairs outside of their own small area of immediate influence.

Endsley (1998) states that automation impacts SA through three major mechanisms: changes in vigilance and complacency associated with monitoring, assumption of a passive rather than active roles in system control, and changes in the form or quality of feedback provided to the operator (Endsley and Kiris, 1995). Additionally, automated systems (due to their complexity) challenge the higher levels of SA (specifically comprehension and projection) during ongoing system operations (Endsley, 1998). Much of this work and the references herein are to complex, dynamic automated systems (eg. nuclear power plants, advanced product manufacturers, air traffic control and medical systems). Planning teams within the Army context will have specific needs of their own that must be catered for in order to ensure the effective implementation of automated tools/systems within the planning loop. Thus, there is a need for people using automated decision aids in this context to be good information processors. There is an indication then that partial automation – particularly in the case of Army planning and decision making – is the desired option. That is, ultimately, the creation of mission plans and the making of critical decisions are better left to the human experts (eg. the commanders overseeing the processes) than the automated tools (see Mosier and Skitka, 1998 for a review of humans and automation).

7. Measures for assessing technological impact

The effects of automated decision aids on the performance of the planning team may be determined in several ways. In terms of hard and soft team performance measures in certain team skill areas, possible metrics (adapted from Table 3-1 in Gregory and Kelly, 1998) might include:

- Making maximum use of time available for planning
- Providing clear and concise mission plans
- Planning for and maintaining flexibility
- Synchronising all assets

In these areas, 'hard' measures are the objective performance measures such as actual time use comparisons, while 'soft' measures include subjective performance assessment measures by trainers or observers.

Other potential groups of 'hard' measures include the performance of the planning team using automated tools. These results can be compared with prior performance without automated tools in order to gauge the tools' effects. These measures should be taken longitudinally in order that:

- Potentially useful tools are not dismissed out of hand due to poor initial performance.
- The learning curve of the planning team can be tracked.
- This learning curve can be applied to predict future teams' training time scales with the same tool.

Some of the performance measures may include items such as the time taken to perform specific actions, the number of movements required to perform actions[5], and the types and numbers of errors being committed by human operators of the tools. Measures of the operator's workload both before and after tool introduction can also be taken, as well as attention load on individual operators. It is the author's intention to combine a variety of these measurements to form a set of paper 'automation evaluation' tools applicable to a variety of situations. That is, situations in which it is desirable to gauge the effect (or potential effect, when dealing with concept demonstrators) of new tools on team performance. As there may be an interaction between the decision-making styles of novice and expert teams and commanders, it is also critical that the methods used be understood and evaluated for their outcomes prior to any introduction of automation. This way, there can be a truer evaluation of the contribution of the tools to the outcomes and processes.

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[5] These both relate to Human Machine Interface issues that can also be examined by interface design evaluations. Any problems encountered can be addressed in recommendations to manufacturers of automated tools.

7.1 Qualitative and quantitative assessment of SA and planning outputs

There are several potential methods for measuring the critical points in the processing and handling of information, and the application of the developed knowledge where Human Factors evaluations can be conducted on the impact of automation on SA and mission planning. Potential measurement methods here include:

- A modified TARGETs[6] methodology (MTM): (refer to Dwyer, Oser, Salas and Fowlkes, 1999; Fowlkes, Lane, Salas, Franz and Oser, 1994; Prince and Salas, 1999)
- The TOM instrument (Team Observation Measure): (refer to Dwyer, Oser, Salas and Fowlkes, 1999; Fowlkes, Lane, Salas, Franz and Oser, 1994)
- Questionnaires to SMEs
- Behavioural observation

7.1.1 The Modified TARGETs Methodology

The TARGETs methodology appears to be a good and fairly objective way of measuring team performance; there is, however, an issue of concern with the implementation of this methodology in an operational environment or during large-scale military exercises. These two settings are vital for the gathering of data under high fidelity conditions, so that the findings can better be generalised to actual military operations; however inserting events into an actual operational situation is nigh on impossible, and into a large-scale military exercise is still very difficult. Therefore, a modified TARGETs methodology is proposed for such situations with the intention of providing a way of accessing TARGETs-type information in a manner that is appropriate for use in the operational military environment.

This modified method involves combining a reordered version of the original TARGETs methodology with observational techniques to produce critical sample events (or a series of these) from a scenario or series of military operations. These are then examined by SMEs and a list of acceptable responses (behavioural or otherwise) for these sample events is produced. The list can then be compared with the responses that actually occurred at the time of occurrence of each sample event/series to determine the level of agreement with the generated list. This can also be compared with a list of responses from the military participants in the event to provide a list of other acceptable responses (i.e. other than the response that has already occurred).

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[6] The TARGETs methodology refers to the Targeted Acceptable Responses to Generated Events tool, which is a checklist that can be individually tailored to each scenario by researchers in conjunction with operational experts. It consists of a list of expected behaviours or responses from crew or team members in response to events within the scenario. The occurrence (or otherwise) of the expected behaviour is checked off during the course of the scenario by raters with no judgements made about the behaviour. This is simple to use but a labour intensive tool to construct.

7.1.2 The Teamwork Observation Measure

The Teamwork Observation Measure (TOM) is derived from several performance measurement techniques developed during such research as the Navy's TADMUS project (Johnston, Smith-Jentsch and Cannon-Bowers, 1997) and aircrew coordination and training (Prince and Salas, 1993). This instrument was designed to test performances for strengths and weaknesses, and to rate performances on critical teamwork dimensions (Dwyer, Oser and Fowlkes, 1995). From empirical validations of this methodology, four dimensions of teamwork have been identified: communication, team coordination, SA, and team adaptability. Each of these dimensions was divided into separate categories, and assessors instructed to provide comments during their observations to be used for critical teaching points during feedback. These included such items as 'out of sequence communications'. The TOM also includes an assessor rating scale for interactions within the team on the four dimensions of teamwork (Dwyer, Oser, Salas and Fowlkes, 1999).

7.1.3 Questionnaires to SMEs

SMEs can be a source of critical information for both the progress of developing systems, and the evaluations performed on those systems. Thus the knowledge SMEs hold should be tapped early into the evaluation cycle, particularly if field data is difficult to obtain or the system is still at the schematic stage.

7.1.4 Behavioural Observation

This is a method commonly used by behaviourists world wide, and can be extremely useful in the military context. It is essential for providing both a snapshot of the behaviours occurring in the situation(s) under investigation and a taxonomy of the behaviours involved in given situations, and can include the timing of given behaviour, the frequency of occurrences of certain behaviours, and the sequences of behaviours. The appropriate data can then be decided upon by the researcher(s) according to the purpose of the evaluation. In examining the impact of automation on mission planning, for example, researchers may take note of the time taken to use system components, the order in which planning behaviours are performed, and the frequency of vital planning behaviours. These things may then be compared in planning teams with and without automated tools, or indeed those with outdated tools compared with demonstrations of future/developmental tools. The focus is both at the individual and at the team level, where team level issues can be identified from the timings of behaviour, the levels of behaviours overall, and the outcomes of these conditions.

8. Conclusions

The understanding, measurement, and facilitation of SA development and maintenance in military teams (and teams of military teams) is not a simple matter. In addition, it is no longer simply a case of examining the team members themselves – there are other agents to be considered in the modern Army. Thus, where the study of shared SA is a complex issue when teams of humans are involved, the interaction of such teams with introduced automation presents an ever more complex picture with which researchers are struggling to come to terms. The ultimate aim of such technological advance is improvement of team performance (through enhanced SA) and the aiding of military functions such that friendly forces have the edge when it comes to confrontation with enemy forces. In order to ensure that performance enhancement is what is *actually* occurring, research needs to delve into the reality of such automation and its impact on the performance of the teams using it. This will be the subject of future research, in addition to related areas such as skill development in the use of such tools, the potential training lead time necessary to maximise human performance in conjunction with these tools, and optimising the design of computer interfaces to facilitate ease of use.

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19. ABSTRACT
Increasingly, the trend for military and other organisations is an increase in automation to improve the efficiency and effectiveness of staff in the workplace. In the military context, automated tools assisting in battlefield visualisation and mission planning may be implemented for these very purposes. Automation may, however, impact on the performance of military teams and affect the situation awareness (SA) necessary for good team functioning. This review examines the potential impacts and benefits of automation on information sharing, SA, planning, and team performance, as well as the concept of measuring SA. Several potential methods for measuring both shared and individual SA in various military contexts (ie. during field exercises, Command Post Exercises and in laboratory-based experiments) are then briefly outlined. It concludes with a brief discussion of the need for further examination of the impact of automation, the need for training of staff, and the reality of the benefits imparted by the tools themselves.

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